2.0 HAZARDS TO AIRCRAFT DURING APPROACH AND LANDING

2.1 Introduction

In the most general of terms, it can be stated that one of the most serious hazards to aircraft flight is that of collision. Frequently of a major or catastrophic nature, the inclusive term of "collision" includes a number of different categories. For example, considering the approach and landing phase, an aircraft might strike high ground, it might inadvertently hit either long or short of the runway, or it might strike another aircraft. Collision with another aircraft could occur either in the air or on the ground. In all of these cases, the usual method of determining the existence of a hazardous situation, and the necessary corrective action, is based on visual observations, primarily outside the cockpit.

Conditions of reduced or degraded visibility due to atmospheric or meteorological effects will, of necessity, seriously compound the difficulty of avoiding the several hazards previously identified. In addition to making the basic problem of hazard detection and avoidance more difficult, poor visibility further aggravates the overall situation by introducing added complexities to the normal traffic flow in the terminal area due to either a slowdown or stoppage of landing operations. Added to their effect on the paramount issue of flight safety is the reflection that these adverse conditions have as operational and economic penalties, due to delays, diversions, traffic build-up and separation problems.

In the following paragraphs the meteorological conditions which affect visibility are discussed. Fog, rain, snow and smog are considered in terms of both the degree to which they can impair visibility and the frequency of their occurrence. Accident statistics are then presented and reviewed for the purpose of determining their possible relationship to poor visibility. They are also studied in a broader sense to determine what system functions and what performance criteria are important in a hazard warning and avoidance system.

2.2 Effects of Meteorological Conditions On Visibility

2.2.1 Fog. - The main meteorological condition that adversely affects aircraft landing is fog. It reduces the range at which the runway is seen through direct attenuation of the visible radiation from the runway and approach lights and through an increase in the background light level produced by scatter from other lights and, during the day, from the sun. The total effect fog has on airline operations depends upon the following parameters:

- Amount by which visibility range is reduced, ie, density of fog.

Duration of Fog

- Frequency of occurrence.

Fog consists of particles of water varying in size from 0.5 to over 60 microns, the number of particles per unit volume and the distribution of sizes varying with different types of fog. But as far as airports are concerned, fog is classified in terms of meteorological visibility or runway visual range, irrespective of the type of fog.

Meteorological visibility is obtained by an observer judging the distance at which various objects can be seen. Runway Visual Range (RVR) may be obtained by an observer counting the number of lights visible along the runway. More accurate information is obtained by measuring the actual attenuation over a fixed path alongside the runway and converting this to give RVR. For purposes of defining visibility conditions in order to establish legal compliance with established minimums at a given airport, the measurement of attenuation is typically made with a transmissometer.

Low cloud along the approach path also reduces visibility in the same way as fog thus, in order to determine whether this will affect landing aircraft, the height of the cloud base above the airport is measured. This height is known as the decision height (DH). The important visibility parameter is, of course, the slant visual range along the approach path which is a function of the horizontal RVR and DH.

The visibility conditions associated with approach and landing are normally described in terms of categories which are composites of RVR and DH. Each category has a minimum value for RVR and for DH. The currently established minimum values for each category are shown in Table II-1.

TABLE II-1. APPROACH MINIMA

Category	RVR	DH (Approach Minima)
Cat I	2400 ft	200 ft
(Interim) Cat II a	1600 ft	150 ft
Cat II	1200 ft	100 ft
Cat III a	700 ft	0 ft
Cat III b	150 ft	0 ft
Cat III c	0 ft	0 ft

The serious effect fog has on airline operations can be shown through evaluation of the meteorological visibility statistics for various airports. For example, at Kennedy International Airport, the records for the past 18 years indicate that the visibility is less than 1/2 mile for an average of 153 hours per year and less than 1/4 mile for an average of 94 hours per year. The figures include poor visibility conditions due to rain and snow. However, the contribution from these phenomena is small.

The performance of approach and landing sensors is affected by the attenuation at the wavelength of the radiation being used. In the case of optical sensors, the level of the background illumination caused by scatter from approach lights and sun light is also important.

It is usual to give the attenuation of fog in terms of its water content, to relate this to meteorological visibility, it is necessary to know the relation between the two. A number of empirical formulae have been given to relate the two; a recent one by Eldrige is as follows (Ref. 1):

$$M = 950/d^{1.54}$$

where M = average moisture content in gm/m^3

d = visibility in feet

Barhydt (Ref.2) and Chu and Hogg (Ref.3) give the following theoretical values for the attenuation through fog at optical wavelengths:

Visible Band (0.5 microns)	3000dB/km/gm/m^3
Far infrared (10 microns)	450dB/km/gm/m^3

Using the above information, the attenuation through fog of various visibilities has been calculated and the results listed in Table II-2. For comparison, the attenuation at four microwave wavelengths is also listed.

The significance of this table is the extreme increase in the attenuation as the wavelength decreases. As shown later on, this severely restricts the range of optical systems in dense fog.

TABLE II-2. ATTENUATION IN FOG (dB/km)

Visible Range (ft)	ILS Category (gm/m^3)	Water Content (gm/m^3)	Radar				Optical	
			X 10 GHz	Ku 16 GHz	Ka 35 GHz	V 70 GHz	10 microns	0.5 micror
2400	I	0.006	very small values				2.7	18
1200	II	0.016	very small values				7.2	48
700	III a	0.04	0.002	0.005	0.025	0.095	18.0	120
150	III b	0.41	0.02	0.051	0.26	0.96	180.0	1210
100		0.80	0.039	0.1	0.51	1.88	360.0	2400

2.2.2 Rain. - Rainfall has to be extremely heavy before the optical visibility through it is reduced to such an extent as to prevent a landing. The rainfall density-visibility relationship has been investigated by a number of workers (Ref.4) and the range of values derived from their empirical formulae are listed below.

TABLE II-3. VISIBILITY IN RAIN

Rainfall Rate (mm/hr)	Visibility Range (ft)
1	38,000 - 42,600
4	15,000 - 15,300
16	5,500 - 5,750
40	2,600 - 3,550
100	1,400 - 1,920

In practice the visibility can be somewhat less than those listed above in the event that windshield clearing mechanisms are either not available or inoperative.

Since the rainfall density has to be relatively high before visibility is seriously affected, it could be argued that it is not essential for a landing aid to operate in rain. This deduction may be valid for those cases wherein the aircraft pass through rain but not cloud (or fog) during the approach and landing phase. However, the pilot will not see the runway when the aircraft is descending through low lying precipitating clouds. For these occasions a sensor which will perform in rain is required. It is the thesis of this study that it is essential for high ground to be detected through rainfall as well; or, if this is not possible, for a climb signal to be generated by the rain itself.

Rainfall produces both attenuation and signal backscatter effects on sensor performance. These are discussed in Volume II, Section 6 and Volume III, Sections 3 and 4 for the microwave frequencies listed below in Table II-4. This table also includes consideration of optical frequencies.

TABLE II.4. ATTENUATION IN RAIN (dB/km)

Rainfall Rate, mm/hr	X	Ku	Ka	V	10μ	0.5μ
1	0.01	0.07	0.3	0.8	1.3	0.8
4	0.05	0.25	1.1	2.4	4.2	2.5
16	0.26	1.3	4.1	7.3	8.6	5.2
40	1.15	3.2	10	16	14	8.5
100	3.24	9.0	20	30	28	17

TABLE II.5. RADAR CROSS SECTION OF RAIN AT 18°C (m^2/m^3)
(Backscatter Effect)

Rainfall Rate, mm/hr	X	Ku	Ka	V
1	1.3×10^{-7}	1.3×10^{-6}	1.8×10^{-5}	2.6×10^{-4}
4	1.0×10^{-6}	1.1×10^{-5}	1.3×10^{-4}	1.9×10^{-3}
16	9.0×10^{-6}	6.0×10^{-5}	6.0×10^{-4}	8.7×10^{-3}
40	4.0×10^{-5}	2.9×10^{-4}	1.3×10^{-3}	1.8×10^{-2}
100	1.8×10^{-4}	9.8×10^{-4}	3.3×10^{-3}	3.6×10^{-2}

The tables show that the attenuation of rain and the backscatter from rain are dependent upon both the rainfall rate and the operating frequency. Both attenuation and backscatter increase with increasing rainfall and with increasing frequency. Thus, the minimum values occur in light rainfall at X band frequencies and the maximum value occurs in heavy rain at V band. The effect of frequency is discussed further in detail in Section 6 (this volume). But in assessing the overall effect on airline operations, it is also necessary to know something of the statistics of rainfall frequency, duration and area of coverage.

The most important factor is the amount of time the rainfall rate exceeds a given value. Other factors of interest are the duration of rainfall of various intensities and the linear extent of various intensities.

A review of typical rainfall statistics shows, for worst case U.S. and worldwide conditions, that rainfall rates can exceed by a significant amount the levels used in present design criteria, i.e., greater than 16 mm/hr. For example, the maximum recorded rainfalls in the U.S. show, for a storm occupying an area of 10 sq. miles, a rainfall of 250 mm in one hour. But these storms occur very infrequently and, as shown in Table II-6, are of short duration. In order to obtain a realistic estimate of the effect rainfall has on airline operations, average rather than extreme statistics have been used.

TABLE II-6. EXPECTED EXTREME RAINFALL RATES FOR VARIOUS DURATIONS (Ref. 5)

Duration (mins)	Rainfall Rate - mm/hr.	
	Gulf Coast	World Wide
1	380	480
5	181	230
10	152	190
30	113	140
60	81	100

From rainfall statistics averaged over a number of years, the total time during which rainfall exceeded the specified rates has been derived for several typical locations and listed in Table II-7, below.

TABLE II-7. RAINFALL DURATION (HOURS PER YEAR)
(From Refs. 5,6)

Rainfall Rate Exceeds (mm/hr)	Miami	Washington	Bedford England	New Orleans
4	--	63	--	90
10	--	11	0.4	--
16	25	--	0.2	37
40	9	--	0.05	17
100	1.7	--	--	--

Table II-7 shows that the duration of rainfall rates greater than 16mm/hr is small, even in places with high annual rainfall such as Miami. In the domestic U.S., localities would not appear to experience rates higher than 16mm/hr for other than relatively short periods of time.

In tropical areas, however, long periods of heavy rainfall occur during the monsoon season. For example, Bombay's rainfall for July, which is the peak of monsoon season, averages 700mm. But if we assume that the rainfall pattern is the same as Miami's then, on the average it exceeds 16 mm/hr in July for only 12 hours. The corresponding figure for 40 mm/hr would be four hours.

This analysis shows that on the average the amount of time per year the rainfall rate exceeds 16 mm/hr is generally quite small, even in areas of heavy rainfall. In addition, the duration of any one period of heavy rainfall tends to be short which further minimizes the effect rainfall has on airline operations except for those cases where an aircraft is terminating its flight following a long overwater leg, has limited reserves and must utilize an alternate which is also in equatorial regions. Consequently, this study considered sensor performance only for rainfall rates of up to 16 mm/hr.

2.2.3 Snow. - Visibility is affected by heavy snowfall and empirical formulae relating visibility range to snowfall rate, expressed by its melted water content, have been given by various researchers. The range of values of snowfall corresponding to optical visibility in feet, together with related attenuation values for pertinent frequencies, are listed in Table II-8. The value of 11dB/km/mm/hr has been assumed for 0.5 micron; (Ref.7) the values given by Gunn and East (Ref.8) have been adopted for the microwave frequencies.

TABLE II-8. SNOWFALL VISIBILITY AND ATTENUATION (dB/km)

Snowfall Rate	Optical Visibility	Radar				Optical
Melted mm/hr	ft.	X	Ku	Ka	V	0.5μ
1	1600-3060	8×10^{-4}	2×10^{-3}	9×10^{-3}	1×10^{-1}	11
4	510-760	3×10^{-3}	7×10^{-3}	7×10^{-2}	9×10^{-1}	44
16	170-190	2×10^{-2}	4×10^{-2}	6×10^{-1}	8	176

The other factor which affects sensor performance in the presence of snow is the radar cross section of the snow. Dry snow consists of ice crystals and, because ice has a lower dielectric constant than water, its radar cross section is below that of rain of equivalent precipitation rate.

The maximum rate of snowfall is, typically, much less than the maximum rate of rainfall. Measurements by Warner and Gunn (Ref.7) show a maximum rate of fall in Montreal of about 5mm/hr (melted) and Wisler and Brater (Ref.9) say in urban areas it rarely exceeds 2.5 mm/hr (melted).

The mean seasonal duration of snowfall exceeding particular rates was determined for this study. However, assuming that half the total fall will be at a rate of greater than 2.5 mm/hr, then during the winter months the amount of time with a significant reduction in visibility is of the order of 20 hours at typical northern latitudes.

Snow does not affect the performance of a microwave sensor as much as does rain of an equivalent rate of precipitation because it has lower attenuation and scattering coefficients. As a general rule it can be assumed that performance in snow (disregarding the effects of snow cover on the ground) will be better than that estimated for 4 mm/hr rain.

2.2.4 Smog. - With stable atmospheric conditions the results of combustion produce a concentration of aerosols in the atmosphere above large urban areas. The necessary stable atmospheric condition is a radiation inversion. This phenomenon typically occurs in Los Angeles during the day; in London it occurs during winter nights. The resulting dense haze is known as smog.

Smog consists of particles 0.01 to 2 microns in diameter. On occasions the concentration can be high enough to reduce optical visibility to below half a mile. Since the particle size distribution is comparable with that of fog, there is a corresponding improvement in relative visibility at the longer infrared wavelengths.

Typically dense smog has an attenuation of up to 17 dB/km at 0.6 microns (Ref.10) which is assumed to fall to 2.5 dB/km at 10 microns. At microwave frequencies attenuation and scattering affects are negligible. Thus smog is very similar to fog of 2400 ft. visibility and, hence, an equipment that operates satisfactorily in this environment operates satisfactorily in dense smog.

2.3 Characteristics of Accidents

2.3.1 Accident Statistics. - Early in 1969, in recognition of the extreme importance a proper interpretation of aircraft accident statistics could have to this project, PNSI subcontracted such an analysis to the Flight Safety Foundation. The basic data contained in the FSF report (Ref.11) to PNSI was previously reported in Ref. 12.

Table II-9 presents one aspect of the statistical evaluation, that of determining just where in the overall flight domain the accidents occurred which might be avoided through hazard warning and avoidance systems. Of the 820 accidents which occurred to certificated air carriers during the period 1958 through 1967, approximately 110 of these were placed in an "applicable" category meaning that the existence of an airborne hazard warning and avoidance system could have significantly contributed to the avoidance of these accidents. The 110 "applicable" accidents were then subjected to further analysis.

As a basis for categorizing accidents by flight phase, six phases of the flight profile were identified in accordance with National Transportation Safety Board (NTSB) practices as follows:

I Takeoff climb - that period from the time the wheels leave runway to the time when the aircraft is configured for climbing to cruise altitude.

II Climb to cruise - that period from the time the aircraft is configured for climb and is ascending to cruise altitude.

III Cruise and inflight descending - includes periods of both cruise and en route descent for the purpose of landing or to change altitude, during which the aircraft is configured for normal cruising.

IV Let-down/initial approach - that period during which aircraft undergoes changes in altitude for the purpose of landing and which takes the aircraft within 10 miles of the airport with the intent of landing.

V Final approach - that phase of the flight profile from 10 miles out from the airport to one and one/half miles from end of runway prior to landing.

VI Landing - from 1 1/2 miles out to touchdown.

TABLE II-9. DISTRIBUTION OF ACCIDENTS -- DOMESTIC AIR CARRIERS (by type of accident and flight phase)

FLIGHT PHASE	MID AIR COLLISION	NEAR MISS	COLLISION WITH GROUND	UNDERSHOT LANDING	THUNDER STORM	TOTALS
PHASE I TAKE-OFF CLIMB	0	0	1	0	0	1
PHASE II CLIMB TO CRUISE	1	4	1	0	0	6
PHASE III CRUISE & INFLIGHT DESCENDING	6	13	6	0	5	30
PHASE IV LET-DOWN/INITIAL APPROACH	1	1	2	0	0	4
PHASE V FINAL APPROACH	4	0	22	0	0	26
PHASE VI LANDING	0	0	1	42	0	43
TOTALS	12	18	33	42	5	110

Types of accidents applicable to the use of airborne radar were defined for the purpose of this study as:

1. Mid Air Collision.

2. Near Miss - flight occurrence where personal injury due to evasive action was sufficient to classify as an accident.

3. Collision with Ground - an accident involving ground contact during flight other than during the landing phase.

4. Undershoot - any accident occurring during the landing where ground contact is made prior to reaching the end of the runway.

5. Thunderstorm related turbulence - an inflight occurrence, where turbulent air conditions in or near thunderstorms caused personal injuries or aircraft damage sufficient to classify as an accident.

Some of the logical questions that could be asked, given a data base of this nature, are:

1. Is there any identifiable group of commercial carrier accidents which, in general, exhibit similar characteristics?

2. What equipment(s) does it appear would be beneficial in preventing more of these accidents?

3. Can we further identify some of the required characteristics of these equipments?

The set of 110 applicable accidents accounted for 37% of all of the human fatalities sustained by domestic air carriers during the 1958-1967 time period. Further, 63% of the applicable accidents occurred during the final approach and landing phases of flight. In the final approach phase the major cause cited was collision with the ground. In the landing phase the major cause cited was undershooting the runway. Tables II-10 and II-11 present a relatively detailed matrix of the approach and landing accident survey, along with some notations concerning the circumstances regarding each accident.

It can be reasoned from an examination of these data that an additional sensing and display device could play an important and critical role in assisting the pilot to avoid high ground and to avoid undershooting the runway. According to the ground rules laid down as regards definition of flight phases, accidents classified as "final approach" (from 10 miles out to 1 1/2 miles from the end of the runway) represented 24% of the 110 applicable cases.

This indicates a definite necessity for a system providing capability for detection of either high ground or runway orientation at ranges up to 10 miles. Extension of the flight phase back beyond 10 miles up to start of let-down only includes 4 additional accidents or 4% of the total. Complete data was not available concerning the weather conditions during all of these incidents, but Table II-10 does indicate the relatively high percentage of accidents reporting either IFR or specific conditions of degraded visibility. The need does exist for some form of sensor/display which could give the pilot, under instrument flight conditions, some warning of the existence of an obstruction to his flight ahead of him along his current velocity vector.

An additional level of performance requirements can be generated from an interpretation of Table II-11 in which landing accidents (from 1 1/2 miles out to the end of the runway) are detailed. These 43 accidents comprise 39% of all of the accidents categorized as applicable to this study. Two aspects of the problem become evident. First, the data available in quantification of the undershoot or hit-short distance indicates the predominance of accidents in which relatively close-in misjudgments were made. In the majority of cases cited, the aircraft struck the ground closer than 400' from the end of the runway. Pilot misjudgment of distance from touchdown represented the most common factor quoted in the accident analysis.

TABLE II-10. APPROACH PHASE, ACCIDENT SURVEY MATRIX

Final Approach

AIRFIELD	AIRCRAFT	OCCURRENCE	CIRCUMSTANCE	PILOT MISJUDGEMENT	WEATHER	DAY/DUSK/NIGHT	LANDING AID
Constance, Ky.	CV880	Coll Gnd	10k Short			Night	
Gt. Falls, Mont.	CV340	Coll Wires/Poles		Alt Err Dist Alt	Low Ceil., Snow		
Saigon, Viet Nam	L1049	MAC					
San Antonio, Texas	DC6	Coll Gnd					
Tourane, Viet Nam	CL44	Coll Gnd					
Newbern, N.C.	M404	Coll Trees	Dark, Unlit				
Constance, Ky.	B-727	Coll Hillside		Failed to Monitor Alt	Visual		
Knob Noster, Mo.	DC-6	Coll Trees	During Maneuver to Align w/Runway, below Runway Altitude	Desc. Below Gl. Sl.	Adverse		ILS
Detroit	C-46	Coll Gnd					
Miles City, Mont.	DC-3	Coll Gnd					
Morgantown, W. Va.	DC-3	Coll Gnd					
Peoria, Ill.	DC-3	Coll Gnd	Turbulence		Thund'stm		
Moses Pt., Alaska	Beech D-18	Coll Gnd	Altimeter Lag		VFR		
Bristol, Tenn.	DC-3	Coll Gnd	Mountain	Lost Position Info.			
Detroit, Michigan	DC-8	Coll Gnd			IFR/VFR, Rain/Glare		
Stuttgard, Germany	DC-7	Coll Gnd		Passed Below Minimum	IFR		
Denver, Colo.	DC-6/Beech 35	MAC					
Missoula, Mont.	DC-4	Coll Gnd		Tried VFR Appr.	IFR		
Sacramento, Cal.	C-46	MAC	Struck by another A/C				
Hickory, N.C.	F-27	MAC	Struck by another A/C		Deteriorating		
Providence, R.I.	DC-4	Coll Gnd	Trees (during go-ar'nd)	Below Minimum	3rd Attempt		
Williamsport, Pa.	M-202	Coll Gnd	Mountain	Didnt Find Head'g	Snow Shower		
Chicago, Ill.	L-1049	Coll Gnd		Rtn.to AP, Tite Mnvr.	Marginal, Low Ceil		
Charlottesville, Va.	DC-3	Coll Gnd		Not in proper IFR appr. area	IFR		
Freeland, Michigan	V-700	Coll Gnd	Stall		Restricted Vision		ILS
Chicago, Ill.	CV-240	Coll Gnd	Off Course				Back Course

TABLE II-11. LANDING PHASE, ACCIDENT SURVEY MATRIX

Landing

Kansas City, Mo.	DC-6	Undershoot		Dist/Alt		Day	
San Juan, P.R.	CV-640	Undershoot		Dist/Alt		Day	
Flushing, N.Y.	B-727	Undershoot	ATC gave incorrect Alt. setting	Dist/Alt	Rain, low Ceiling		
New Orleans, La.	DC-8	Undershoot		Dist/Sp/Alt		Day	
Salt Lake City, Utah	B-727	Undershoot	Poor Planning, excessive Descent Rate			Dusk	
Charlotte, N.C.	DC-7	Undershoot		Dist/Sp/Alt		Day	
Stevens Pt., Wis.	DC-3	Undershoot	Below Minima (235' low)				VOR
Ponce, P.R.	CV-340	Undershoot		Dist/Alt		Day	
Weyers Cave, Va.	M-404	Undershoot		Dist/Alt		Day	
Sacramento, Cal.	B-720	Undershoot		Dist/Sp/Alt	Clear	Day	
Kansas City, Mo.	B-707	Undershoot		Dist	VFR	Day	
Richmond, Va.	DC-7	Undershoot		Dist/Alt		Dusk	
LaGuardia, N.Y.	DC-6	Undershoot	Failure to Plan & Execute				VASI
Karluk, Alaska	G-44	Undershoot		Dist/Speed		Day	
Calgary, Canada	F-27	Undershoot	No Data				
Indianapolis, Inc.	DC-6	Undershoot		Dist.	Gusty	Day	
San Francisco, Cal.	L-1049	Undershoot	Below Minima		Marg, fog		ILS
Grand Island, Nebr.	CV-340	Undershoot		Fail.to Monitor Alt.	Fog, instr app	Night	
Pow 'B" Rdr St., Alaska	C-18	Undershoot		Dist	600 ft, 7mi vis	Day	
New Orleans, La.	B-720	Undershoot		Dist	5mph wind	Day	
Rocky Mt., N.C.	M-404	Undershoot		Dist/Speed		Day	
Manila, P.I.	B-707	Undershoot		Dist	"normal"	Day	
Wake Island	CL-44	Undershoot		Dist		Night	
Adak, Alaska	L-1049	Undershoot	Ignored Warnings	Dist/Alt	Above min	Night	PAR
Ft. Lauderdale, Fla.	B-720	Undershoot		Dist		Day	
Jacksonville, Fla.	DC-7	Undershoot	Improper Instru. App'ch		Gnd fog, smk		
Shemya, Alaska	DC-6	Undershoot	Runway Lights Out		At minimum	Night	GCA, Inadeq. info to pilot
Bismark, N.D.	DC-3	Undershoot		Dist	Visual&dry	Day	
St. Louis, Mo.	B-707	Undershoot	Inadequate Airspeed	Flare		Day	
Houston, Texas	B-720	Undershoot	Inadequate Supervis'n by C'ptn	Approach		Night	
Pittsburgh Pa.	Viscount	Undershoot		Landing		Day	
LaGuardia, N.Y.	L-188	Undershoot	Badly Planned Approach			Day	
Houston, Texas	DC-7	Undershoot				Day	
New York, N.Y.	DC-7	Undershoot	Too Low Failed to Correct in Time.			Day	
Wash. D.C.	DC-7	Undershoot			Clear		
Riverhead	B-707	Undershoot	Hit Localizer Shack			Day	
Juneau, Alaska	B-377	Undershoot				Day	
Kotzbue, Alaska	C-46	Undershoot					ADF
Chicago, Ill.	B-707	Undershoot			35-40kts Crosswind	Day	
LaGuardia, N.Y.	L-188	Undershoot					ILS Bk Crs, A/P eng.
New Orleans, La.	DC-7	Coll Gnd	Tried Go-Ar'nd		Fog		ILS
Columbus, Ohio	M-404	Undershoot	Snow on Runway			Day	
Nantucket, Mass.	CV-240	Undershoot	Fld.to Abandon.1/8 Mile Vis		Adverse		ILS

Of the 43 landing accidents, 25 occurred in what was termed "daytime" conditions. The conditions of visibility were not further qualified. If this categorization could be interpreted as VFR conditions, then the suggestion could certainly be advanced that the pilot undershot the runway even though he was looking at it. The display then, must provide more than just a pictorial representation of the runway, it must provide in great measure a flight director representation of the real-time deviation from the prescribed horizontal and vertical flight paths.

The general conclusion to be drawn from this brief resume of the existing accident statistics is to verify the requirement for a system whose hazard warning functions encompass both final approach and landing phases of flight back as far as 10 miles from the end of the runway. As many as 63% of the applicable accidents studied in this investigation could have been avoided by the proper application of an airborne system which provided both high ground avoidance and runway approach and landing guidance.

2.4 Summary

2.4.1 Meteorological Effects. - The meteorological data provides the following indications with regard to hazard warning and avoidance systems.

1. Dense fog severely restricts optical visibility.
   - It is necessary that the IALM operate through heavy fog.
2. Heavy rain does not seriously degrade optical visibility unless accompanied by fog or low clouds.
   - When heavy rain accompanies fog, it is necessary that the IALM operate through both.
   - It is necessary that the high-ground avoidance mode operate reliably in heavy rain.
3. Rainfall of 16 mm/hr is taken as a reasonable maximum value for this study. Much heavier rains do occur but with small probability of occurrence and short durations.
4. The attenuation of falling snow is less than for rainfall of equivalent water content. Heavy snow has a water content equal to only a few mm/hr of rainfall. A reasonable attenuation for snow is somewhat less than that of 4 mm/hr of rain.
5. Smog is similar to fog with a visibility of 2400 ft.
   - Smog should not be a factor in either Cat II or Cat III operations.

2.4.2 Accident Statistics. -

1. 820 accidents occurred to certified air carriers during the period of 1958 to 1967.

2. 110 of these accidents were "applicable" to the concept of hazard avoidance through the use of airborne sensors.

   These 110 accidents accounted for 37% of all of the human fatalities sustained in the 820 accidents.

3. 63% of the applicable accidents occurred during the final approach and landing phases of flight.

4. 24% of the applicable accidents occurred in final approach (10 mi to 1 1/2 mi from the runway) and typically in poor visibility.

   There is a need for detection of either high-ground or runway orientation at ranges up to 10 miles. Few accidents occur beyond 10 miles.

5. 43 of the applicable accidents occurred in the landing phase of flight. Of these, 25 occurred in "daytime" conditions with misjudgment being cited as the major cause.

   Assuming that "daytime" implied that the pilot could see the runway, it follows that seeing the runway is not enough. Further, in conditions of poor visibility, a pictorial presentation of the runway would also be inadequate.

   It is concluded that a situation display is required as a reasonable minimum level of information. Further, to avoid adding workload, it would be necessary to sense the situation and thus display some form of command information to the pilot.